EFFECT OF STORAGE TIME IN DIFFERENT HUMIDITY CONDITIONS ON MECHANICAL AND PHYSICAL PROPERTIES OF HYBRID MEDIUM DENSITY FIBREBOARD (MDF)

by

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MDF	Medium density fibreboard
UF	Urea Formaldehyde resin
PF	Phenol Formaldehyde resin
EFB	Empty Fruit Bunches
OPT	Oil Palm Trunks
OPF	Oil Palm Frond
PFF	Presses Fruit Fibre
POME	Palm Oil Mill Effluent
DP	degree of polymerization
MMC	Metal Matrix Composites
PMC	Polymer Matrix Composites
CMC	Ceramic Matrix Composites
MEKP	Methyl Ethyl Ketone Peroxide
ABS	Acrylonitrile Butadiene Styrene
C	Carbon
H	Hydrogen
O	Oxygen
N	Nitrogen
MRB	Malaysian Rubber Board
PORLA	Palm Oil Registration and Licensing Authority

UDC	Undirectional Composite
MMC	Metal Matrix Composite
FFB	Fresh fruit bunch
IB	Internal Bonding
MPOB	Malaysian Palm Oil board
TS	Thickness Swelling
WA	Water Absorption
SEM	Scanning Electron Microscopy
ASTM	American Society for Testing and Materials
BSEN	British Standard European Norm
FAS	Fibre Analysis System
MC	Moisture Content
MOR	Modulus Of Rupture
MOE	Modulus Of Elasticity
RH	Relative Humidity
RW	Rubberwood

KESAN KAJIAN MASA PENYIMPANAN PADA KEADAAN KELEMBAPAN YANG BERBEZA TERHADAP SIFAT MEKANIKAL DAN FIZIKAL BOD GENTIAN BERKETUMPATAN SEDERHANA TERHIBRID.

ABSTRAK

Dalam penyelidikan ini, papan gentian berketumpatan sederhana (MDF) terhibrid telah dihasilkan dengan menggunakan gentian kayu getah (RW) dan gentian tandan kosong buah kelapa sawit (EFB) berasaskan berat kering ketuhar. Gentian termo-mekanikal yang diperoleh dari Lembaga Kelapa Sawit Malaysia (MPOB) dan Merbok MDF Sdn Bhd telah digunakan untuk menghasilkan Komersial MDF terhibrid berketebalan 12mm. Ketumpatan purata bod yang dihasilkan adalah 650 kg/m^3. Resin Urea formaldehid digunakan untuk menghasilkan bod tersebut dengan 12% kandungan resin. Terdapat 4 jenis MDF yang dihasilkan mengikut nisbah masing-masing iaitu EFB: RW, 20: 80, EFB: RW, 50: 50, EFB: RW, 100:0, EFB: RW, 0:100. Tiga jenis kelembapan bandingan (RH) yang berbeza digunakan untuk menyimpan bod iaitu 65% RH, 93% RH pada suhu tetap 20˚C dan keadaan normal (Suhu purata, 23˚C-30˚C; RH, 64%-80%). Objektif eksperimen ini adalah untuk mengkaji kesan sifat-sifat gentian terhadap kekuatan mekanikal dan fizikal MDF terhibrid dengan menggunakan mesin Sistem Analisis Gentian (FAS). Selain itu, tujuan eksperimen ini dijalankan adalah untuk mengkaji kesan masa penyimpanan dan perbezaan kelembapan bandingan terhadap kekuatan mekanikal dan fizikal MDF terhibrid sebelum dan selepas penyimpanan. Eksperimen ini juga dijalankan untuk mengkaji kesan masa penyimpanan dan perbezaan

kelembapan bandingan terhadap struktur anatomi gentian MDF terhibrid sebelum dan selepas penyimpanan dengan menggunakan Mikroskop Elektron Penskanan (SEM). Kesan masa penyimpanan dan perbezaan RH pada MDF terhibrid dikaji dengan mengukur perubahan yang berlaku kepada sifat mekanikal dan fizikal MDF terhibrid tersebut pada selang masa 2 minggu sehingga 10 minggu. Sifat mekanikal yang dikaji ialah ikatan dalaman (IB) dan kekuatan lenturan. Manakala sifat fizikal ialah kandungan lembapan (MC), pembengkakan ketebalan (TS) dan penyerapan air (WA). Mikroskop Elektron Penskanan (SEM) dan Sistem Analisis Gentian (FAS) digunakan untuk mengkaji struktur anatomi gentian yang digunakan untuk menghasilkan MDF terhibrid. Keputusan secara umumnya menunjukkan MDF terhibrid daripada kayu getah memberikan kekuatan mekanikal dan fizikal yang terbaik berbanding dengan bod yang lain manakala, MDF terhibrid daripada EFB menunjukkan penurunan sifat mekanikal dan fizikal yang tertinggi. Pada 65% RH, MDF terhibrid menunjukkan kesan perubahan sifat mekanikal dan fizikal yang terendah. Namun begitu, MDF terhibrid menunjukkan penurunan sifat mekanikal dan fizikal yang tinggi pada 93% RH. Mekanisma yang berlaku ini akan dibincangkan selanjutnya.

EFFECT OF STORAGE TIME IN DIFFERENT HUMIDITY CONDITIONS ON MECHANICAL AND PHYSICAL PROPERTIES OF HYBRID MEDIUM DENSITY FIBREBOARD (MDF)

ABSTRACT

In this research, hybrid medium density fibreboard and medium density fibreboard (MDF) were produced by using rubberwood (RW) and empty fruit bunch (EFB) based on oven dried weight. RW fibres were obtained from Merbok MDF Sdn Bhd in Kedah. While, EFB fibres used to produce those board were obtained from Malaysian Palm Oil board (MPOB) in Bangi. Commercial 12mm thick hybrid medium density fibreboard and medium density fibreboard (MDF) were produced using thermomechanical pulp fibre. The average density of these boards were 650 kg/cm. The resin used was commercial urea formaldehyde with 12% resin content. Those MDF were prepared by dry process. There are 4 different ratio of MDF from rubberwood and EFB used that are EFB: RW, 20: 80, EFB: RW, 50: 50, EFB: RW, 100:0, EFB: RW, 0:100. Three different relative humidity (RH) at 65% RH, 93% RH with fixed temperature at 20°C and normal condition (Average temperature, 23°C-30°C; RH, 64%-80%) were used to store the boards. There are 3 objectives of this research such as to study the effect of fibre properties on mechanical and physical properties of hybrid medium density fibreboard using Fibre Analysis System (FAS), To determine the effect of storage time and different relative humidity on mechanical and physical properties of the

hybrid medium density fibreboard before and after storage and to investigate the effect of storage time and different relative humidity on morphology of the hybrid medium density fibreboard before and after storage using Scanning Electron Microscope (SEM). The effect of storage time and relative humidity of MDF were assessed by measuring the changes of the board mechanical and physical properties for 10 weeks at two week's interval. The mechanical tests involved were internal bonding (IB) and flexural test. While, physical tests were moisture content (MC), thickness swelling (TS), water absorption (WA). Scanning Electron Microscope (SEM) and Fibre Analysis System (FAS) were used to study the anatomical of fibre structure of hybrid MDF. The results showed that, MDF produced from rubberwood exhibited the superior mechanical and physical properties as compared to other boards. Whereas, MDF produced from EFB showed the most substantial decreased on mechanical and physical properties after 10 week storage as compared to other MDF. In addition, at 65% humidity, MDF exhibited lower effects on the mechanical and physical properties of the panel. While, at 93% humidity panel exhibited a decreased in the dimensional stability and mechanical properties of the board. Possible mechanisms behind this reduction are discussed.

CHAPTER 1

INTRODUCTION

1.1 Medium Density Fibreboard (MDF): An Overview

Medium density fibreboard (MDF) is a dry formed panel product manufactured from lignocellulosic fibres combined with a synthetic resin such as Urea Formaldehyde resin (UF), Phenol Formaldehyde resin (PF) or isocyanate binder under heat and pressure in the presence of moisture (Maloney, 1993; Ye *et al.*, 2007; Halvarsson *et al.*, 2008). In recent years, great changes have taken places in the MDF industry. Production of this product has increased dramatically and new plants are planned worldwide. MDF is commercially successful due to its superior properties such as environmental friendly, wide applications including furniture and moldings, moderate overall density, suitable density profile, straight-edged flat conventional composite, good resin content result and finishing result (Krzysik *et al.*, 2001). MDF is used extensively in factory-assembled and ready to-assemble furniture as well as cabinets, underlayment, drawer fronts and counterdrops. Moreover, MDF is replacing thin plywood and wet-process hardboard in the production of molded and flush door-skins (Halvarsson *et al.*, 2008).

In Malaysia the production of MDF remains intact, at over 1.2 million m^3. Malaysia is presently one of the biggest suppliers of MDF in the world. Presently, the majority of MDF producers in Malaysia are using rubberwood as their raw material. The country now has eight MDF mills which are using rubberwood as their major raw material (Mohamad *et al.*, 2003 and Thole and Hora, 2005). Rubberwood has a light straw to

light brown colour with density that varies from 550 to 650 kg/m^3 and has the strength properties associated with other medium density hardwoods. The average diameter is normally 30 to 35 cm and the length of the trunk is 3 to 5 m (Ridzuan *et al.*, 2002). Due to these superior properties, rubberwood has become one of the major raw material in manufacturing MDF. Projection shows that in the near future the supply of rubberwood will not meet the demand for making. MDF Therefore, one possible solution in order to overcome this problem is by using other type of biomass or waste raw material which is abundant in Malaysia. According to Sopian *et al.* (2005), there are five major sectors that contribute to the waste of biomass energy in Malaysia such as cultivation area, forestry, rubber cultivation, paddy cultivation, sugarcane cultivation, cocoa cultivation and coconut cultivation. Amongst these biomass, oil palm cultivation area show the highest abundant supply of biomass resources.

The oil palm industry in Malaysia with its 6 million hectares of plantation produces over 11.9 million tones of oil and 100 million tones of biomass. The biomass from oil palm residue include the oil palm trunks (OPT) and fronds (OPF), kernel shell, empty fruit bunch (EFB), pressed fruit fibre (PFF) and palm oil mill effluents (POME). In addition, the total crop of fresh fruit bunch is more than 30 millions tones per annum, which generate more than 10 million tones of EFB. Only 10% of the EFB is used and the rest are abandoned (Hariharan *et al.*, 2004 and Wan Asma and Wan Rasidah, 2007). At present, EFB is mainly used as mulch, but the economic are marginal due to the high transport cost. It is seldom burnt as fuel as the shell and fruit fibres are sufficient for the oil palm mill (Abdul Khalil and Rozman, 2004).

In common with wood and wood-based composites the mechanical and physical properties of MDF are affected by environmental factors such as humidity, storage times and temperature. For instance it has been shown that exposure to condition of high relative humidity results in an increase in the moisture content and thickness swelling as well as decrease in flexural strength and internal bonding strength (Seco and Barra, 1998). Moisture problem arises due to wood being a naturally hygroscopic material. In service, these products can be exposed to a range of environmental conditions. The relationship between moisture content and strength properties is very important if panel products are to be used as structural members subjected to atmospheric moisture changes (Pritchard *et al.,* 2001).

Some basics aspect that have been inspect by previous research using lignocellulosic fibres in manufacturing MDF have been reported by Seco and Barra, 1998; Koh and Yeo, 2000; Paridah *et al.,* 2000; Krzysik *et al.,* 2001; Pritchard *et al.,* 2001; Thole and Hora, 2005. Moreover, treated EFB use in manufacturing other composite also have been reported by Hill and Khalil, 2000; Rozman *et al.*, 2004; Sreekala *et al.*, 1997; Hariharan *et al.,* 2004. In addition, there are also a study which are focus on the properties of MDF from EFB but it only include properties of MDF based on two different resin content was reported by Ridzuan *et al.*, 2002. However, until now the comprehensive study still have not been done on the properties changes of new hybrid MDF made form EFB and rubberwood towards relative humidity, temperature and storage time. All these properties are very important information about the possibility of using EFB and rubberwood as an important material in manufacturing MDF in Malaysia and worldwide.

1.2 Objectives of the research

Properties of medium density fibreboard (MDF) have been studied extensively by researchers throughout the world. However, in this study hybrid MDF was produced by using different ratio of rubberwood and empty fruit bunches (EFB). Studies on properties of hybrid MDF towards temperature and different relative humidity is still new and not many researches have been published. The main objectives of this research are summarized below:

a) To study the effect of fibre properties on mechanical and physical properties of hybrid medium density fibreboard using Fibre Analysis System (FAS).

b) To determine the effect of storage time and different relative humidity on mechanical and physical properties of the hybrid medium density fibreboard before and after storage.

c) To investigate the effect of storage time and different relative humidity on morphology of the hybrid medium density fibreboard before and after storage using Scanning Electron Microscope (SEM).

CHAPTER 2

LITERATURE REVIEW

2.1 Composite Material

Composite materials have been used for many thousands of years, starting with natural ones such as wood, bone and horn. Besides, the advantages of deliberately combining material to improve or modified properties were appreciated by some of the earliest civilization (Matthews and Rawlings, 1994; Khairiah *et al.*, 2005 and Khalid *et al.*, 2008). Ancient Pharaohs made their slaves use bricks with straw to enhance the structural integrity of their buildings (Sharma, 2000). Moreover, ancient society, imitating nature used this approach as well. They used the straw to reinforce mud in brickmaking, without which the brick would have almost no strength (Roylance, 1996).

Nowadays, composites are used in minor structures of aerodromes. Conventional construction of composites ought to cost much less in the future and will not be constraint. High performance composites are highly reliable which have strength to weight ratios higher than other materials (Sharma, 2000). The advantages of composite materials appear when the modulus per unit weight (specific modulus) and strength per unit weight (specific strength) are considered. The higher specific modulus and specific strength of composite material means that the weight of components can be reduced. The reduction in weight resulted in greater efficiency and energy saving (Hull, 1981; Kickelbick, 2007 and Gomez-Romero and Sanchez, 2007).

2.1.1 Definition of Composite

The term composite could mean almost anything if taken at face value, because all material are composed of dissimilar subunits if examined at close enough details. In modern materials engineering, the term composite usually refer to a matrix material that is reinforced with fibres. Many composites used today are at the leading edge of materials technology with performance and costs appropriate to ultrademanding applications (Roylance, 1996 and Khalid *et al.*, 2008). Besides, according to Weidmann *et al.* (1990), a composite material consists of a matrix material which encapsulate discrete element of one or more different materials. These element can be particles, fibres, assemblies of fibres, sheet or in case of foam. In addition, composite also is defined as a material composed of two or more distinctly identifiable constituent. Composite that form heterogeneous structures which meet the requirement of specific design and function, imbued with desired properties which limit the scope for classification (Sharma, 2000 and Kozlowski and Maria, 2008). A more detail description of a composite material was given by Schwartz (1992) and Sreekala *et al.* (2002) who defined a composite material is a material brought about by combining material differing in composition or form on a macroscale for the purpose of obtaining specific characteristic and properties.

2.1.2 Classification of Composite

Based on the definition of a composite material, composites can be produced by any combination of two or more materials which can be metallic, organic or inorganic. Schwartz (1992) and Kickelbick (2007) cited that there are five general classification of composites such as :

  i)   Fibre composites, composed of fibres with or without a matrix.

  ii)   Flakes composites, composed of flat flakes with or without a matrix.

  iii)   Particulate composite, composed of particles with or without a matrix.

  iv)   Filled (or skeletal) composites composed of continuous skeletal matrix filled by a second material.

  v)   Laminar composites composed of layer or laminar constituent.

Generally composite materials are classified based on the morphology of reinforcement and also on the matrix material. Classifications of composite materials according to the reinforcement forms are particulate reinforced composites, fibre reinforced composites and structural composites. Particles by definition are non-fibrous in nature and have roughly equal dimensions. Common shapes of particles used as reinforcements in composites are spherical, cubical, tetragonal, platelet or of other regular or irregular

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shapes. Fibre reinforced composites are composed of reinforcing fibres which are a characterized as a long fine filament with an aspect ratio of greater than 10 (Harper, 1996). Glass, carbon, aramid, boron and cellulose fibres are widely used as reinforcement in composite materials. Structural composites though, consist of laminate and sandwich composites, which are used in structural engineering applications. In addition, classification of composite materials based on the type of the matrix can be grouped into there main categories such as metal matrix composites (MMC), polymer matrix composites (PMC) and ceramic matrix composites (CMC) (Schwartz, 1992 and Hull, 1981). According to Hull (1981) most composites in industrial use are based on polymeric matrices.

2.2 Matrices

Matrix can be easily defined as a material where the reinforcing system of a composite is embedded. The matrix serves as a binder which holds the reinforcing materials in its place. Beside that, when a composite is subjected to an applied load, the matrix deforms and transfers the external load uniformly to the fibres (Harper, 1996 and Shwartz, 1992). The matrix also provides resistance to crack propagation and damage tolerance owing to the plastic flow at crack tips (Shwartz, 1992). Furthermore, the matrix also functions to protect the surface of fibres from adverse environmental effects and abrasion especially during composite processing. Matrix resin which provides the continuous phase of the composite is expected to serve the following functions such as (Sharma, 2000):

i) Provide a uniform distribution of structural and environmental load to the reinforcing fibre through a good adhesion and strong interface with the reinforcement.

ii) Protect the surface of a composite against abrasion, wear and tear and corrosion and can initiate fracture.

iii) Absorb the impact of loads and minimize stress concentration by enhancing the fracture toughness.

iv) Resist high temperature and withstand repeated cycling operations, especially under hygroscopic conditions and thus prevent or delay the growth of microcracking in the composite.

Polymers matrices can generally be classified into two major types which are thermoplastics and thermosets. Under the influent of heat, matrix thermoset at first soften and later harden permanently. In contrast, matrix thermoplastic stay soft as long as their heating is continued and harden when cold. The selection criteria of the matrices depend solely on the composite end use requirements. For example, if chemical resistance together with elevated temperature resistance is needed for a composite material then thermoset matrices are preferred than thermoplastics. Whereas, if a composite material with high damage tolerance and recyclability is needed then thermoplastics are preferred (Sharma, 2000).

2.2.1 Matrix Thermoset

Thermosetting adhesive are supplied as liquid, pastes and solid (in film form). This liquid resin is then converted to a hard rigid solid by chemical cross-linking through a curing process which involves the application of heat and the addition of curing agents or hardeners. Once cured, a tightly bound three dimensional network structure is formed in the resin and hence the resin cannot be melted, reshaped and reprocess by heating (Hull, 1981). The advantages of thermosetting polymers for engineering applications are high thermal stability, rigidity and dimensional stability (Asri and Khalil, 2003 and Hull, 1981). They can be retained in partially cured condition too for over extended periods of time; rendering thermosets are very flexible (Sharma, 2000). Thermoset resins are produced by controlled reaction of their constituent which is interrupted before completion. The intermediate product is condensed to a viscous liquid, dried and reduced to powder. Continuation and completion of the reaction take place during adhesion by application of heat, catalyst or both. Catalyst or hardener such as acid, paraformaldehyde, ammonium salt or other chemical which are added to control the time between spreading and pressure as well as the temperature required for adhesion (Tsoumis, 1991). Among the most common thermosetting resins used in composite manufacturing are unsaturated polyesters, epoxies, vinyl esters and phenolics.

2.2.1.1 Urea Formaldehyde

Urea Formaldehyde (UF) is available in liquid or powder form. This type of resin hardens both at room and high temperature, 95˚C to 130˚C. Resins hardening at low

temperature utilized strong acid as catalyst but such acid may attack the wood (Tsoumis, 1991). UF are not suitable for exterior use, but its performance maybe improved by adding 10% to 20% melamine-formaldehyde or resorcinol formaldehyde. Besides, it produced joints that are colourless or have light brown colour and are resistant to microorganism. The resin maybe used for fast adhesion and it is lower in cost compared to other thermoset resin (Shields, 1984 and Pizzi, 2003d). Principally, UF resin is significantly cheaper than other resins. More over, it is tolerant of the conditions under which it cures. There is considerable latitude regarding temperature and speed of cure, viscosity, solid content, etc. The mole ratio of urea and formaldehyde can be adjusted, as can the acid catalyst and buffering systems, to cure boards under the desired conditions of high temperature (> 100˚C) and low pH (Pizzi, 2003c and Walker, 1993).

However, this type of resin has a moderate blunting effect on cutting tool. Moreover, UF has relatively poor resistance to long periods of wetting and it emits vapors which maybe hazardous to health. According to Tsoumis (1991), the emission is affected by the molar ratio of formaldehyde to urea. This ratio varies from 1.2:1 to 2.0:1. Resins with a low ratio have a lower free formaldehyde content and longer pot life. However they are slower to cure and produced joint of lower strength, stiffness and durability. Besides, UF polymers have relatively poor heat resistance and discolour and degrade if maintained continuously above 80˚C. In practice, straight UF resin is used in the preparation of moulding composition and adhesive (Saunders, 1985). The method employed to produce this resin varied according to the end-use. The reaction between urea and formaldehyde is divided into two stages. The first is the alkaline condensation to form mono-, di- and trimethylolureas (Sharma, 2000).

The second, polymer building stage is the acid (pH 4-6) condensation of the methylolureas. When condensed these form ether (— O —) links between molecules, some of which contain methylol (CH₂OH) end groups enabling the reaction to proceed to form long chain molecule of UF which become cross-linked by the formation of methylene (- CH₂ -) bridges. Before the resin is fully cured, the reaction is arrested by neutralizing the solution, final hardening being achieved in hot press and by the addition of a catalyst to reduce the pH sufficiently to ensure rapid cure (Pizzi, 2003c). The rate of reaction varies according to the pH. pH range from 5 to 8 is for molar ratio of 1: 1 for urea-formaldehyde and pH ±6.5 is for 1:2 molar ratio of urea-formaldehyde (Sharma, 2000). Figure 2.1 showed the formation of urea formaldehyde from reaction of urea and formaldehyde.
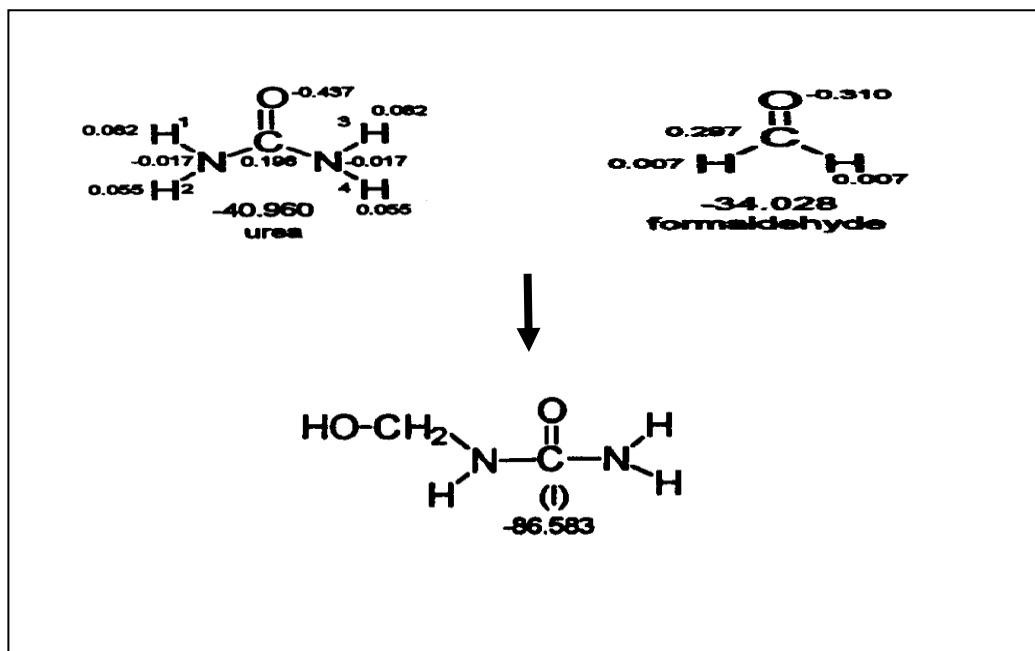
Figure 2.1: Reaction of urea and formaldehyde (Pizzi, 2003c).

2.2.1.2 Other Thermoset resin

Besides urea formaldehyde (UF) resin there are other resins which are commonly used in composite manufacturing such as unsaturated polyester, epoxies and phenol formaldehyde (PF). Epoxies resin is a group of reactive compound that is characterize by the presence of the oxirane group. They react with suitable hardener to form cross link matrices which exhibit high strength and excellent adhesion to a wide range of substrate (Goulding, 2003). The largest single use is for surface coatings, which account for about 50% of current epoxy resin output. Other applications include laminated circuit boards, carbon fibre composites, electronic component encapsulation and adhesives (Mark and Bikales, 1970). In a typical process for the preparation of a liquid epoxy resin, a mixture of bisphenol A and epichlorohydrin (about 1:4 molar) is heated to about 60˚C. When epichlorohydrin react with a difunctional phenol such as bisphenol A the above reaction leads to linear polymers. In order for such polymers to be commercially useful as epoxy resins it is necessary that the polymers are terminated by epoxy group. This is achieved by carrying out the polymerization with a molar excess of epichlorohydrin (Saunders, 1985). Epoxy resin are capable to perform at high temperature at range from 125 to 175˚C depending on the composition (Schwartz, 1992). Moreover, they are reasonably stable to chemical attacks and are excellent adherents having shrinkage during curing and no emission of volatile gases. These advantages, however make the use of epoxies rather expensive (Sharma, 2000).

PF polymers are polymers formed by the interaction of a phenol, or a mixture of phenols and formaldehyde. The initial reaction usually takes place at 2-, 4- or 6- position (Pizzi,

2003c). Commercial material is most commonly based on phenol itself. Other phenols such as cresols, xylenols and resorcinol are used to a limited extent. It may be noted that several aldehydes other than formaldehyde have been used to prepare phenol polymer but none has attained appreciable commercial significance (Saunders, 1985). Hardened PF resin has specific gMenonty of approximately 1.2 to 1.3, reactive index 1.6 and specific heat of 0.5 (Pizzi, 2003b). It is available as a liquid (dark red in colour) or a powder or in the form of film (Tsoumis, 1991). Currently it is used as nonstructural applications in automotive industry especially for highly stressed, elevated temperature (150 to 200˚C) applications (Schwartz, 1992). This resin has very low evolution of formaldehyde, both during manufacture and in finished board. However, phenolic resin are more expensive, slower curing and required higher press temperature than urea formaldehyde which are greater than 200˚C (Walker, 1993). These resins are the most important of synthetic adhesives. They are preferred binder for products such as outdoor-grade plywood, electrical laminate, abrasive wheel, brake linings and glass insulation (Mark and Bikales, 1970 and Sreekala *et al.*, 2002).

Unsaturated polyester is prepared commercially by the reaction of a saturated diol with a mixture of an unsaturated dibasic acid and a modifying dibasic acid. The unsaturated acid provides sites for subsequent cross-linking. The function of modifying acid is to reduce the number of reactive unsaturated sites along the polymer and hence to reduce the cross-link intensity and brittleness of the final product. Some acids and anhydride which are used to modify polyester are, in fact unsaturated but the double bonds are not sufficiently reactive to represent sites for subsequent cross-linking (Saunders, 1985). Liquid polyesters are stored at room temperature for an extended time and the mere

addition of a catalyst can cure the matrix material within a short time. Selection of catalyst and the amount of catalyst to be used depends on the temperature at which the resin is to be cured, pot life and gelation time. Generally, methyl ethyl ketone peroxide (MEKP) cause the complete cure of polyester resin at lower temperature (Pizzi, 2003e). Polyester resin is quite easily accessible, cheap, and finds use in a wide range of fields. They are used in automobile and structural applications. The cured polyester is usually rigid or flexible and transparent. Polyester withstands the variation of environment and is stable against chemicals. The resin can be used about 75˚C or higher depending on the application (Sharma, 2000). Today, unsaturated polyester are widely used as adhesives for thermoset plastic bonding and metal bonding.

2.2.2 Matrix Thermoplastic

Thermoplastic has one or two dimensional molecular structure and its tend to soften at elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperature can be reversed to regain its properties during cooling. Moreover, the advantages of thermoplastic system over thermosets are that there are no chemical reactions involved, which often result in the release of gases and heat. Manufacturing process is limited by the time required for heating, shaping and cooling the structure (Sharma, 2000). Thermoplastic derive their strength and stiffness from the inherent properties of the monomer unit and exhibit high molecular weight (Asri and Khalil, 2003 and Hull, 1981). The advantages of thermoplastic resin are can be recycle and easier to process. However, they exhibit larger degree of expansion and contraction (Sharma, 2000).

Thermoplastics can be classified into two classes which are commodity plastics and engineering plastics. Commodity plastics such as polyolefins, styrenics, acrylics and vinyls possess moderate mechanical and thermal properties. Thus, they are normally used in applications with less service requirements. Engineering plastics on the other hand are able to perform at elevated temperatures and under high load bearing. Examples of engineering plastics are ABS and Nylon. They consist of long, discrete molecules which melt to a viscous liquid at the processing temperature typically 500˚ to 700˚F or 260˚ to 371˚C. After forming they are cooled to an amorphous, semicrystalline or crystalline solid. The degree of crystallinity has a strong effect on the final matrix properties (Schwartz, 1992). In future, thermoplastic will offer a great potential in composite manufacture, since it is easier and faster to heat and cool. Currently, thermoplastics are used primarily with discontinuous fibre reinforcements such as chopped glass or carbon. Pizzi (2003a) cited that there is great potential for high-performance thermoplastic reinforced with continuous fibres. For example, thermoplastic could be used in place of epoxies in the composite structure of the next generation of a fighter aircraft. Table 2.1 showed the properties of thermoset and thermoplastic resins.

Table 2.1: Some typical properties of thermoset and thermoplastic resins

	Epoxy	Polyester	Nylon (6.6)	Polypropylene
Density (g/cm^3)	1.1-1.4	1.1-1.5	1.1	0.9
TensileStrength (MPa)	35-90	45-85	60-70	25-38
Young's Modulus (GPa)	2.1-6.0	1.3-4.5	1.4-2.8	1.9-1.4
Strain at break (%)	1-6	2	40-80	300

1- Schwartz, 1992.

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2. 3 Additives

The changes in temperature and humidity have lead to the serious construction problem due to the warping and shrinkage of the wood based panel. Various oils and water proofing compounds have been introduced to offset these difficulties. Various form of pitch, rosin, turpentine, paraffin, wax, glues and asphalt have also been used (Brown, 1950). Currently the wood based panel industry uses paraffin wax to improve the dimensional stability of the panels. However, the hydrophobic properties of paraffin waxes have a short time effect, resulting in a simple delay in water absorption (Garcia *et al.*, 2005). Numerous types are available which are derived from mineral, vegetable, petroleum sources or synthetic low molecular weight polymer which is compounded with elastomers to improve their flexibility (Shields, 1984). Walker (1993), cited that chemical such as ammonium phosphates and zinc borates are used as a fire retardant in wood composites. While, preservatives such as boron provide durability for wood composites.

2.4 Lignocellulosic Fibre

Natural fibrous material such as wood, oil palm fibre (Oil palm trunk, oil palm frond, empty fruit bunch, etc), jute, hemp, banana, pineapple and sisal are renewable and available in abundance in a million tones per annum. Natural fibres are renewable with ease of processability. They have low density, light weight, non abrasive, non hazardous and capable of recycleability. Moreover, they are low cost and biofriendly characteristic with ideal reactive surface chemistry as compared with man made fibre (Abdul Khalil *et*

al., 2004). Main disadvantage of lignocellulosic material is dimentional instability due to change in moisture content. This is due to the interaction of cell wall polymer which contains hydroxyl group and other polar group that interact with moisture through hydrogen bonding (Abdul Khalil *et al.*, 2004).

2.4.1 Chemical composition of lignocellulosic fibre

The principal chemical elements of wood are carbon (C), hydrogen (H), oxygen (O) and small amount of nitrogen (N). Carbon, hydrogen and oxygen combine to form the principal organic substance namely cellulose, hemicelluloses and lignin. A certain amount of extraneous organic substance in the form of extractives and inorganic matter, obtained in form of ash form remaining constituents (Tsoumis, 1991).

2.4.1.1 Cellullose

Cellulose is a natural polymer containing thousands of β-D- glucose units linked by glucosidic linkages (C-O-C) at the C_1 and C_4 position by the loss of water molecule. Each unit is rotated through 180˚C with respect to its neighbour, so that the structure repeat itself every two units (Figure 2.2). This rotation also able the cellulose chain to pack together to form a crystalline structure. The dimmer (the pair of units) is called cellubiose. Cellulose is a high molecular weight homopolymer of glucose and it is laid down in microfibrils where extensive hydrogen bonding between the cellulose chains produces a strong crystalline structure (Figure 2.3) (Lilholt and Lawther, 2003).
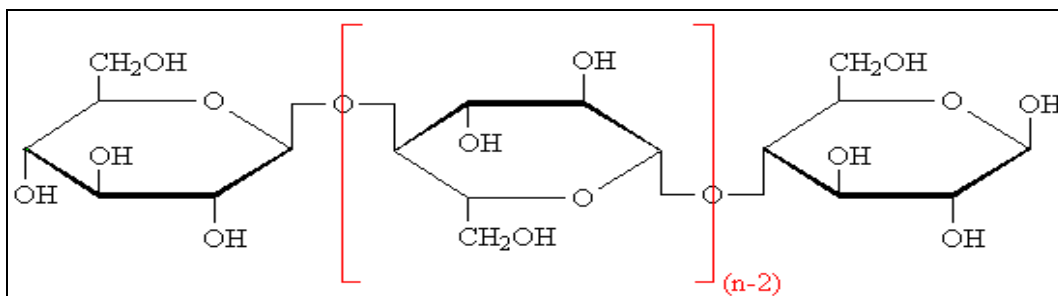
Figure 2.2 : Structure of cellulose (Mishra *et al.*, 2004).
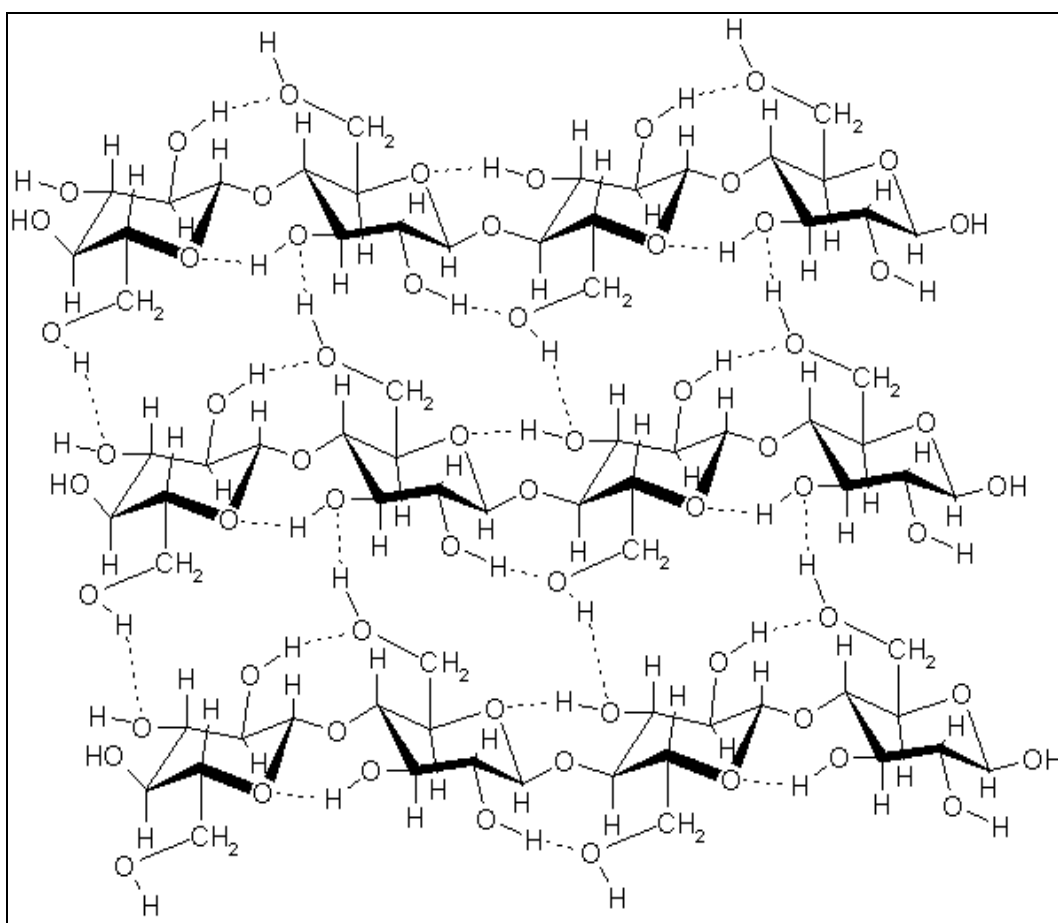
Figure 2.3 : The crystalline structure (Morvan *et al.*, 2003).

According to Bledzki *et al.* (1999) and Morvan *et al.* (2003), cellulose can be characterized as cellulose I, cellulose II, cellulose III and cellulose IV based upon their physical crystal structure. Cellulose contains approximately 10^4 units in the polymer chain and is about 5µm long. Cellulose forms about 40 % to 50 % by weight of dry wood substance. The degree of polymerization (DP) in plant cellulose is between 7000 to15 000 and in wood is estimated around 10 000 (Hearle and Peters, 1963 and Mishra *et al.*, 2004).

2.4.1.2 Hemicellulose

The molecule of hemicelluloses are like cellulose but the degree of polymerization is much smaller than cellulose at around 200 (Sjostrom, 1993). Hemicellulose composed of a variety of monosaccharide such as D-glucose, D-mannose, D-xylose, L-arabinose and D-galactose. Hemicellulose is soluble in water due to the amorphous structure in hemicellulose. Beside that, the constituents of hemicellulose vary from plant to plant (Tsoumis, 1991).

2.4.1.3 Lignin

Lignin is an aromatic substance which is almost totally insoluble in most solvents. It cannot be broken to monomeric unit even when hydrolyzed. Lignin has a disordered structure and is formed through ring opening polymerization of phenyl propane monomers as shown in Figure 2.4. Lignin also provides rigidity, hydrophobicity and decay resistance to the cell wall of lignocellulose fibres. The physical and chemical

characteristic of lignin within the cell wall is an important factor which influent various aspect of MDF manufacturing such as refining and hot press (Walker, 1993 and Koch and Kleist, 2001).
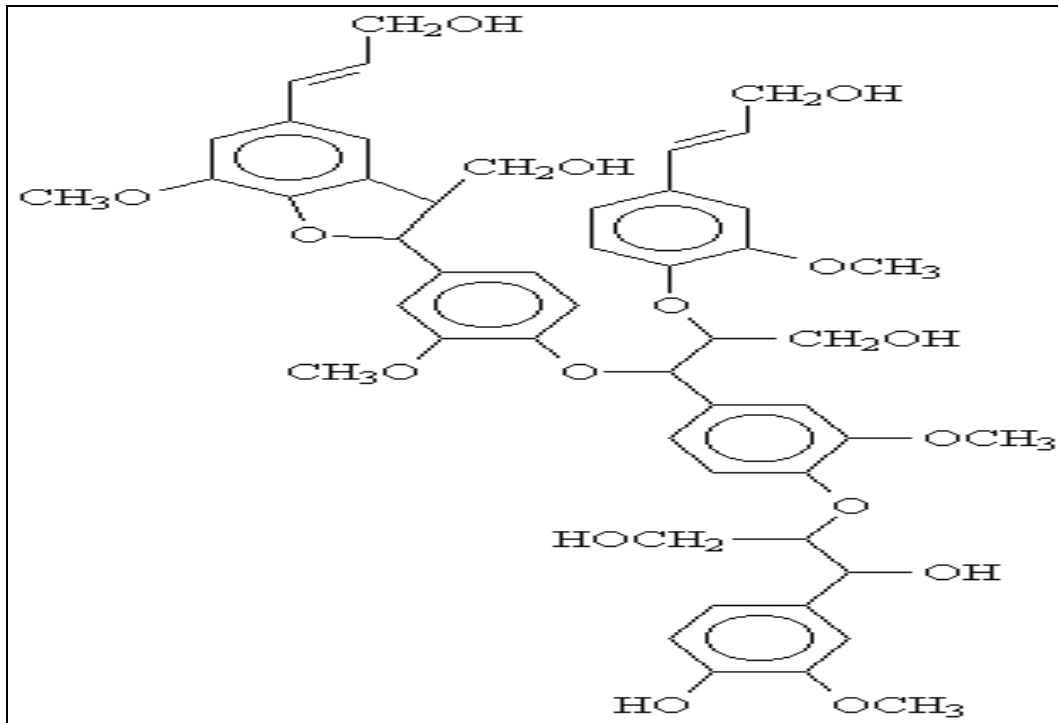
**Figure 2.4** : Structure of lignin (Koch and Kleist, 2001).

2.4.1.4 Extractives

Extractives are compound of varying chemical composition such as gums, fats, resins, sugars, oils, starches, tannin, and alkaloid. The proportion of extractives in wood varies from 1 % to 10% of the oven dried weight of wood. However in some tropical species, the amount of extractives is nearly 20% (Tsoumis, 1991).

2.4.2 Organization of chemical constituents within the cell wall

Crystalline cellulose forms the microfibril core, which is surrounded by hemicellulose and lignin. The microfibril are arranged within a number of layers in the cell wall. The cell wall structure consists of middle lamella, primary wall and secondary wall, as shown in Figure 2.5.
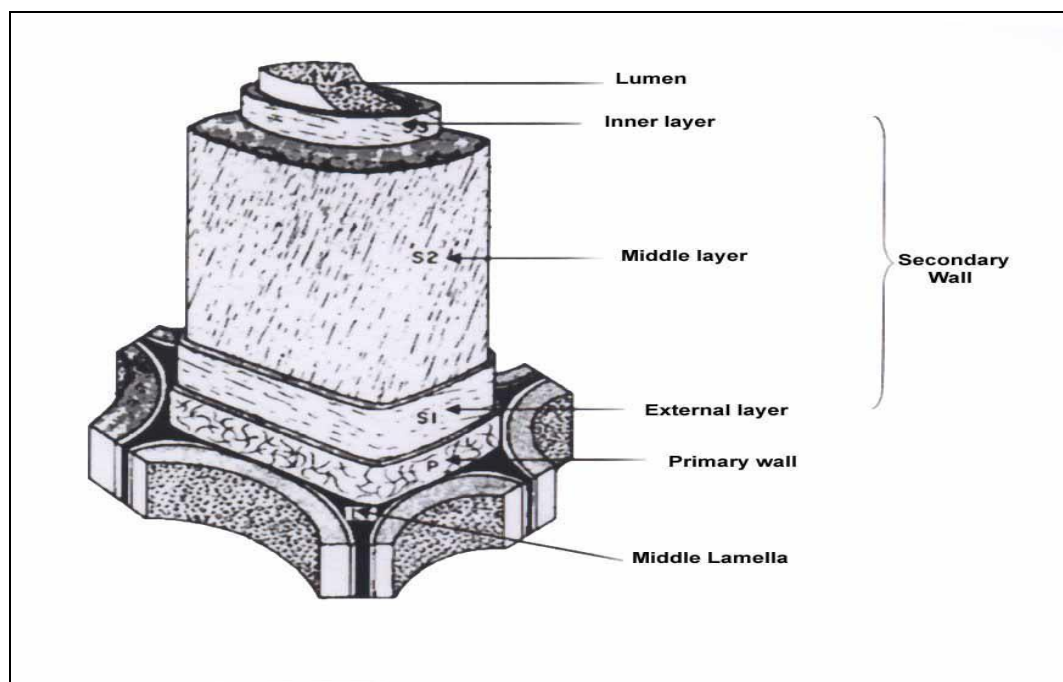
Figure 2.5 : Cell wall structure (Tsoumis, 1991).

Secondary cell wall consist of three layers S_1, S_2 and S_3. Microfibril is arranged in the helices which influence many of the wood properties such as strength properties and dimensional stability especially in S_2 layer. Lignin content is higher in the middle lamella (Dickison, 2000). Whereas, in the secondary wall the amount of lignin in low about 10 % to 20 %. The lignin concentration is lower in S_2 layer than either in the S_1 or

S_3 layer. This is due to the highly regular packing of microfibrils in the S_2 layer leaves less room for the deposition of lignin (Grunwald, 2002). While, the proportion of hemicellulose is high in middle lamella and primary wall where cellulose content is lowest. Cellulose is mostly concentrated in the secondary wall about 50 % to 60 % (Tsoumis, 1991). Extractives are not a component of cell wall substance. They present in cell wall cavity or in cell wall layer (Walker, 1993 and Koch and Kleist, 2001). The chemical composition of some common lignocellulose fibres are summarized in Table 2.2.

Table 2.2: Chemical composition of some common lignocellulose fibres

Fibres	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)
Oil palm empty fruit bunch fibre	19	-	19	2
Coir	32-43	0.15-0.25	40-45	-
Banana	63-64	19	5	-
Sisal	66-72	12	10-14	0.8
Jute	64.4	12	11.8	4-10
Pineapple	81.5	-	12.7	-
Flax	71.2	18.6	2.2	5-12

1- Sreekala *et al.,*1997

2.4.3 Physical and Mechanical Properties of Lignocellulose Fibres

Normaly, the diameter of lignocellulosic fibres is in the range of 0.015 x 10^4 to 0.05 x 10^4 μm and the densities is in the range 1.25 to 1.55 g/cm^3. The mechanical properties of lignocellulose fibres are summarized in Table 2.3. According to Sreekala *et al.* (1997) and Bledzki *et al.* (1999), the mechanical properties of lignocellulose fibres depend on the fibrillar structure, spiral angle of the micro-fibrils and the cellulose content.

The relationship between the strength of the lignocellulose fibres with the microfibrillar angle and cellulose content is given by equation 2.1 below:

$$\sigma = -334.005 - 2.830\theta + 12.22W \tag{2.1}$$

where σ is the fibre strength, θ is the microfibrillar angle and W is the cellulose content. Furthermore, the elongation at break ε can be correlated with the microfibrillar angle, θ based on equation 2.2 below :

$$\varepsilon = -2.78 + 7.28 \times 10^{-2}\,\theta + 7.7 \times 10^{-3}\,\theta \tag{2.2}$$

According to Bledzki *et al.* (1999) and Lilholt and Lawther (2003), the strength of lignocellulose fibres were strongly affected by various factors such as the structure of the fibres (amorphousness), orientation of molecular chains, imperfection or defects in the fibres and the degree of polymerization. The higher cellulose content and smaller spiral angle would result in the increase of the lignocellulose fibre strength (Bledzki *et al.,* 1999). The regions with non-crystalline structure such as the amorphous regions in the cell wall of the lignocellulose fibres are considered as weak points due to low number of chains per cross sectional area which are unable to withstand the stresses effectively. The orientation of the crystalline components influences the strength of the fibres. High strength fibres are normally achieved with alignments within about 5^{0} of perfect orientation. The defect of the fibre structure such as the presence of fibre bundles which results in non uniform stress distribution. The Mechanical and physical properties of lignocellulose fibres and synthetic fibres are summarized in Table 2.3.